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The Impact of Happy and Angry Faces on Working Memory in Depressed Adolescents

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Abstract

Recent cognitive models suggest that the ability to control emotional information in working memory (WM) may be implicated in the etiology and maintenance of depression. However, few studies have examined the effects of processing relevant and irrelevant emotional stimuli on WM performance in depressed adolescents. In the current study, depressed (n = 27) and healthy (n = 49) adolescents completed two versions of an emotional n-back task: a low WM load (0-back) and high WM load (2-back) task. In the emotion-relevant condition participants were asked to attend to the emotional expression of an angry, happy or neutral face, while in the emotion-irrelevant condition participants were asked to attend to the gender of the face. The results showed a WM improvement for happy faces in the emotion-relevant condition and a WM impairment for happy faces in the emotion-irrelevant condition for healthy adolescents, but not for depressed adolescents. No biases towards angry faces were found. These results demonstrate that depressed adolescents do not show a preferential processing of angry faces, but rather fail to show a positivity bias as seen in healthy adolescents. This supports the theoretical notion that a depressive disorder is characterized by a blunted reactivity towards positive information and may provide new insights into the underlying mechanisms of youth depression.

Keywords. Depression, Adolescence, Working Memory, Positivity Bias

The Impact of Happy and Angry Faces on Working Memory in Depressed Adolescents

Major depressive disorder (MDD) is among the most severe and debilitating mental disorders, constitutes a high economic burden, and increases significantly in prevalence during adolescence (AACAP, 2007). Previous studies reported recurrence rates up to 75% (Curry et al., 2011; Fombonne, Wostear, Cooper, Harrington, & Rutter, 2001a) and showed a six-fold higher risk of suicide associated with adolescent depression (Fombonne, Wostear, Cooper, Harrington, & Rutter, 2001b), emphasizing the need for further research on underlying mechanisms of MDD in this age group. The model of Beck (1976) suggests that automatic information processing, driven by 'depressogenic' self-referent schemas, is a key mechanism in the development of depressive disorders. Compelling evidence supports the existence of negative biases in different aspects of information processing in (subclinically) depressed youth and demonstrates an attentional bias and an interpretation bias for negative information (for a review see Platt, Waters, Schulte-Koerne, Engelmann, & Salemink, 2017).

It has been suggested that impaired cognitive control, and an inflexible working memory (WM) regarding the processing of emotional stimuli in particular, alters the effect of processing biases on depression vulnerability (Lonigan & Vasey, 2009; Salemink & Wiers, 2012) and impacts one's capacity to deal with intense emotion (De Raedt & Koster, 2010; S. M. Levens & Gotlib, 2010). More specifically, it is stated that updating the contents of WM is essential to reorient attention towards or away from emotional stimuli and to reinterpret emotion-eliciting situations (Joormann & D'Avanzato, 2010). Therefore, a flexible WM is hypothesized to affect one's emotion regulation abilities and, in turn, the risk of developing MDD (Joormann, Yoon, & Siemer, 2010; Koster, De Lissnyder, Derakshan, & De Raedt, 2011). This is consistent with the conceptualization of WM as the processes that allow an individual to briefly store, manipulate or update information, necessary to perform complex cognitive or behavioral tasks (Baddeley, 2010).

In the context of emotional information, WM is often assessed using an emotional variant of an n-back task, in which participants are presented with a series of stimuli and are asked to indicate whether the current stimulus matches the stimulus presented n-trials before. Whereas studies in adults document clear associations between impaired updating of the emotional content of WM and depression (Joormann & Gotfib, 2008; Joormann, Levens, & Gotlib, 2011; S. A. Levens & Phelps, 2008; S. M. Levens & Gotlib, 2010; Linden, Jackson, Subramanian, Healy, & Linden, 2011), studies on emotional WM in adolescents have been scarce and findings have been mixed (Ladouceur et al., 2005; Tavitian et al., 2014). Using an n-back task Ladouceur et al. (2005) reported slower reaction times (RTs) to neutral target stimuli in the presence of negative background scenes in depressed adolescents and slower RTs in the presence of positive background scenes in healthy adolescents. These results demonstrate that irrelevant negative information interferes with WM performance in depressed adolescents (i.e., *negative bias*), while irrelevant positive information hampers WM performance in healthy adolescents (i.e., *positivity bias*). In contrast, regarding accuracy rates, Tavitian et al. (2014) showed that, in comparison with healthy adolescents, depressed adolescents' WM performance on neutral target stimuli was less accurate in the presence of neutral distractor faces but not with angry or happy distractor faces. Thus, this study indicates that irrelevant neutral information impairs WM performance in depressed adolescents, while irrelevant positive and negative information does not.

Noteworthy is that the emotional stimuli in prior WM studies mostly served as distractors during the performance of a non-emotional task (Joormann & Gotfib, 2008; Kerestes et al., 2012; Ladouceur et al., 2005; Tavitian et al., 2014). Arguably, however, the influence of emotional stimuli on cognitive control processes depends on the task-relevance of these stimuli (Kanske, 2012). When emotional stimuli serve as distractors and are irrelevant, performance will be impaired due to their preferential processing. However, when emotional stimuli are relevant and require attention, their automatic and prioritized processing will have beneficial effects on task performance (Cromheeke & Mueller, 2014). Interestingly, S. M. Levens and Gotlib (2010) used an emotional n-back task to explore depressed individuals' ability to update WM with new and *relevant* affective information. Depressed participants were faster to integrate relevant negative information in WM (i.e., performance improvement for relevant negative stimuli) and were slower to remove no-longer-relevant negative information from WM (i.e., performance impairment for irrelevant negative stimuli). Healthy adolescents, however, showed the reverse pattern and were slower to disengage from no-longer-relevant positive information in WM (i.e., performance impairment for irrelevant positive stimuli). While comparative studies in mood-disordered adolescent are currently lacking, a couple of studies in healthy adolescents explored the effects of both *relevant* and *irrelevant* emotional information and indicated WM improvement for happy faces when emotion was task-relevant (Cromheeke & Mueller, 2016; Mueller, Cromheeke, Siugzdaite, & Boehler, 2017) but an impairment for these stimuli when they were task-irrelevant (Cromheeke & Mueller, 2016), indicating a positivity bias in healthy participants.

Besides task-relevance of emotional stimuli, also the level of cognitive load of a task is of importance, whereby specifically under high WM demands a reduced ability to suppress irrelevant emotional stimuli is expected (Eysenck, Derakshan, Santos, & Calvo, 2007; Kerestes et al., 2012; Lavie, 2010). Therefore, the current study compared the effects of *relevant* and *irrelevant* emotional stimuli on WM in depressed and healthy adolescents using two versions of an emotional n-back task: *a low WM load* (0-back) and a *high WM load* (2-back) task.

The investigation of emotional processing in WM is of particular interest since it has been shown that the capacity to control incoming information in WM positively impacts one's ability to deal with stressful events and to manage emotional responses (Pe, Raes, & Kuppens, 2013; Schmeichel & Tang, 2015). This emotion-regulating role indicates that a flexible and well-functioning WM represents an important buffer in the onset of mental health problems and suggests that targeting basic cognitive process may improve the effectiveness of depression prevention programs (Pe, Koval, & Kuppens, 2013). Moreover, it is highly relevant to study these processes in an adolescent age group, given that adolescence represents a particularly vulnerable period for the development of a depressive disorder (Merikangas et al., 2010). Part of this increased vulnerability can be found in ongoing brain development that is characterized by an imbalance between an early maturation of subcortical "affective" regions, such as the amygdala, and a late maturation of prefrontal cortical regions involved in cognitive control processes (Casey et al., 2010; Shulman et al., 2016).

Unlike a great deal of previous work on depression-related cognitive control impairments including *sad* faces as negative stimuli, the current n-back study sought to examine the effects of *angry* faces on WM processes. The specific focus on angry faces is based on the fact that these emotional stimuli can be associated with the depression-related schemas of social rejection and thus may elicit a depressive reaction (Hames, Hagan, & Joine, 2013; Platt, Murphy, & Lau, 2015). Sad faces, in contrast, are mood-congruent and may be perceived less personally relevant to depressed adolescents as they simply depict the emotional state of another person (Leyman, De Raedt, Schacht, & Koster, 2007).

Based on cognitive theories of depression (De Raedt & Koster, 2010) and the results of prior emotional n-back studies in depressed adolescents and young adults (Ladouceur et al., 2005; S. M.

Levens & Gotlib, 2010; Tavitian et al., 2014), we hypothesized an impairment in the processing of negative information in WM in depressed adolescents compared to healthy adolescents in a high WM load task. In an *emotion-irrelevant* (gender) focus condition, we expected angry faces to be more distracting and to impair WM performance more so in depressed adolescents compared to healthy adolescents. In an *emotion-relevant* (valence) focus condition, we expected a performance improvement for angry faces in depressed adolescents compared to healthy adolescents. Moreover, based on previous studies showing a WM bias towards positive information in non-depressed individuals, we expected that healthy adolescents would show a WM performance impairment for happy faces during the gender condition (Ladouceur et al., 2005; S. M. Levens & Gotlib, 2010) and a WM performance improvement for happy faces during the valence condition (Mueller et al., 2017; Pe, Koval, et al., 2013).

Material and Methods

Participants

Fifty-three healthy adolescents (28 girls; mean age = 14.21, *SD* = 1.48) and 57 referred adolescents (21 girls; mean age = 14.68, *SD* = 1.62) participated in the study. Thirty-five healthy adolescents were derived from the study of Cromheeke and Mueller (2016), the other participants from the healthy group (*n* = 18) were recruited through advertising in schools. The referred adolescents were recruited from different clinical centers and were invited if they were referred for treatment of internalizing problems. Inclusion criteria for *all* participants were: (a) age between 10-18 years and (b) IQ within the normal range (≥ 70). The Child Behavior Checklist (CBCL; Achenbach & Rescorla, 2001) and the “depressive disorders module” of a semi-structured interview for DSM-5 disorders (SCID-Junior; Braet, Wante, Bögels, & Roelofs, 2015) were used for the screening of psychopathology and the assessment of depressive disorders, respectively. In order to have a refined depressed and healthy group, only *referred* adolescents that met DSM-5 criteria for a diagnosis of depression, either in the present (i.e., current diagnosis of depression) or in the past (i.e., episode of depression in the past) (n = 41) and *healthy* adolescents that did not present clinical symptoms of psychopathology or a depressive disorder (n = 50) were included in the final sample. The research protocol was approved by the Ethics Committee of the University Hospital. Youngsters signed informed assent while legal guardians signed informed consent. After completing the questionnaires and the task, participants were compensated with two cinema tickets.

Self-report measures

Depressive symptoms. The Children's Depression Inventory (CDI; Kovacs, 1992; Dutch version by Timbremont & Braet, 2002) is a 27-item self-report questionnaire designed to assess depressive symptoms in youth. The CDI showed good psychometric qualities in terms of internal consistency and test-retest reliability in non-clinical samples (Craighead, Smucker, Craighead, & Ilardi, 1998; Timbremont & Braet, 2002)(Cronbach's alpha present sample was α = .93).

Anxiety symptoms. The trait version of the State-Trait Anxiety Inventory for Children (STAI-TC; Bakker, Wieringen, Ploeg, & Spielberger, 2004; Spielberger, 1973) is a 20-item self-report questionnaire that assesses the frequency and intensity of anxiety symptoms. The STAI-TC is considered as a reliable and valid measure for assessing anxiety symptoms in youngsters (Cronbach's alpha of .89).

Caregiver-report measures

General psychopathology. The Child Behavior Checklist (CBCL) is a caregiver-report questionnaire measuring emotional and behavioral problems in children and adolescents aged 6 to 18 years (Achenbach & Rescorla, 2001; Dutch version by Verhulst, Ende, & Koot, 1996). It consists of 113 items, which are scored on a three-point scale and represent 8 syndromes of psychopathology. The scores on these syndrome scales can be summed up to calculate a dimensional score for internalizing problems, externalizing problems, and total problems. Additionally, DSM-oriented scales can be computed measuring affective problems, anxiety problems, somatic problems, attention-deficit/hyperactivity problems, oppositional problems, and conduct problems. These scales appear to be a valid and reliable screening measure for DSM-IV disorders (Achenbach & Rescorla, 2001; Nakamura, Ebesutani, Bernstein, & Chorpita, 2009). In this study, the CBCL Total Problem scale was used in the analyses. Internal consistency for the CBCL Total Problems scale was good with a Cronbach's alpha of .88.

Clinical interview

Depressive disorders were assessed using the SCID-Junior (Braet et al., 2015). This semi-structured interview for DSM-5 disorders is a recent modification of the Kid-SCID (Hien et al., 1998), a widely used diagnostic interview for DSM-IV disorders in children that has moderate to good inter-rater reliability and internal consistency (Roelofs, Muris, Braet, Arntz, & Beelen, 2015; Smith, Huber, & Hall, 2005; Van Vlierberghe, Braet, Goossens, & Mels, 2008).

Intelligence

An intelligence score was calculated by using an abbreviated version of the Dutch Wechsler Intelligence Scale for Children III (WISC-III; Kort, 2002). This shortened version has been found to be reliable and valid (Sattler, 1992; Strauss, Sherman, Spreen, & Spreen, 2006) and consists of two subtests: Vocabulary and Block Design.

Emotional n-back task

The present emotional n-back task has been used previously to examine the behavioral (Cromheeke & Mueller, 2016) and neural correlates (Mueller et al., 2017) of affective working memory in healthy adolescents vs. adults. The present version was identical to the one used in the behavioral version (Cromheeke & Mueller, 2016). The 2-back task was programmed in Presentation software and was run on a 15.6" Dell laptop. The pictorial stimuli for the experimental trials were selected from two validated databases: the NimStim (Tottenham et al., 2009) and the Radboud Faces Database (Langner et al., 2010). For the practice trials, 14 faces were selected from the Karolinska Directed Emotional Faces database. Each actor posed three emotional expressions, resulting in a final stimulus set of 33 neutral faces, 33 happy faces and 33 angry faces. The pictures were set at 320 x 440 pixels and were grayscaled.

The participants completed two versions of the emotional n-back task: a 0-back and a 2-back task. In both versions of the task, there were two conditions: a *gender* condition in which participants had to focus on the gender of the faces and a *valence* condition in which participants had to attend to the emotional expression of the faces. In the 0-back task, participants were asked to respond to a target. In the *gender* condition the target was a male of a female face (e.g. is this a male face?), while in the *valence* condition the target was an angry, happy or neutral facial expression (e.g., is this an angry face?). Participants were instructed to press the left mouse button if the presented face was the target, and the right mouse button when the presented face was not a target. In the *gender* condition of the 2-back task, participants were asked to compare the gender of the current face with the gender of the face presented two trials before. In the *valence* condition of the 2-back task, participants had to indicate whether the emotional expression of the current face matched the expression of the face presented two trials before. The 2-back task consisted of match and mismatch trials. A match trial refers to a trial in which the faces or gender are the same, a mismatch trial refers to a trial in which the faces or gender are different. Participants were asked to press the left mouse button for a match trial and the right mouse button for a mismatch trial. Pictures were presented for 2000 ms, with a 500 ms intertrial interval (see Figure 1).

To avoid differences in difficulty of the gender and valence attention condition, only two emotions were shown in each block (angry and neutral, happy and neutral or angry and happy faces). The 0-back task consisted of 12 blocks of 12 trials. Each of these blocks comprised a different combination of emotions (angry-neutral, happy-neutral or angry-happy faces), condition (focus on gender or valence) and target (one of both emotions or gender categories). The 2-back task consisted of 6 blocks of 32 trials with each block being a different combination of emotions (angry-neutral, happy-neutral or angry-happy faces) for each condition (gender or valence). The order of WM load versions (0-back or 2-back) was counterbalanced across participants and within the WM load versions adolescents started either with the gender or the valence condition. Moreover, within the conditions, combinations of emotions were shown in a random order. Finally, and in order to avoid familiarity effects and confusion with identity, each actor was presented only once in a block.

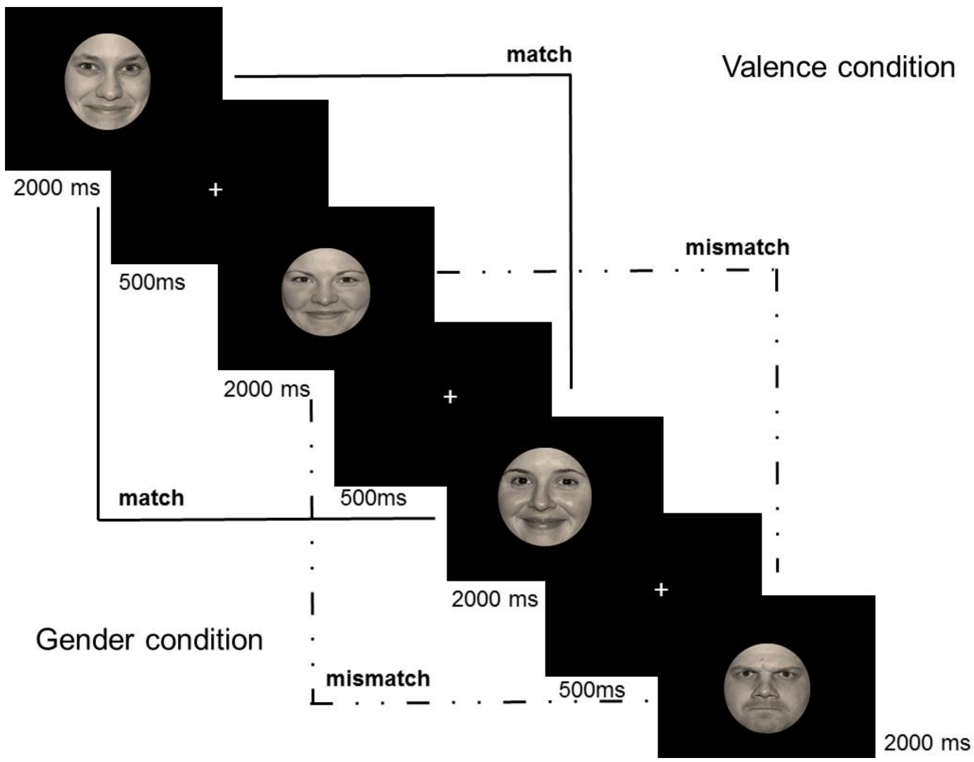

Fig 1 Experimental design of the emotional 2-back task. In the valence condition, match trials refer to trials in which the emotional expression of the target picture matches the emotional expression on the picture two trials back. In the gender condition, match trials refer to trials in which the gender of the target picture matches the gender of the picture that appeared two trials earlier. Pictures were presented for 2000 ms, with a 500 ms intertrial interval

Procedure

Healthy adolescents were invited to the lab at the Faculty of Psychology and Educational Sciences, while referred adolescents were tested in a neutral room at the treatment center. After signing assent/consent, participants were seated in front of a computer and task instructions were displayed on the computer screen. To ensure clarity of the instructions, these were also repeated orally by the experimenter. Before starting with the experiment proper, participants completed practice trials and were able to ask for help if needed. The practice blocks consisted of 10 trials for the 0-back task and 24 trials for the 2-back task. Analogous to a prior n-back study of Mueller et al. (2017), participants could only continue with the experimental blocks if they had an accuracy rate of at least 60% on the practice blocks. After finishing the n-back task, all participants completed the Vocabulary and Block Design test of the WISC-III. At the end of the experiment, subjects completed the CDI and the STAI-TC.

Data Analyses

Data were log10 transformed because of non-normal distribution. A repeated-measures analysis of covariance (RM-ANCOVA) with Load (0-back, 2-back), Condition (gender, valence), and Emotion (angry, happy, neutral) as within-subjects factor and Group (depressed, healthy) as between-subjects factor was conducted for the mean correct RT and accuracy (% correct), separately. Age and intelligence score of the participants were included as standard covariates in all analyses. Moreover, since depression and anxiety are frequently associated with one another (AACAP, 2007), we reran the analyses with anxiety symptoms as measured by the STAI-TC as a covariate of no interest. In addition, to control for the influence of other co-occurring symptoms (e.g., somatic problems) besides anxiety symptoms, the overall level of symptoms on the CBCL Total Problems scale was included in the analyses. Finally, because of gender differences in the neural processes of cognitive control (Koch et al., 2007; Li et al., 2009), gender was also added as a covariate of no interest. Importantly, all abovementioned covariates were entered simultaneously in one model. Since the interactions with group (depressed vs. healthy) remained unchanged, the results of these additional analyses are not further discussed. To further investigate significant interactions, paired-samples *t*-tests were performed. Finally, to assess the contribution of symptom severity, correlation analyses were performed between CDI and STAI-TC scores and the different performance variables. Effects sizes are provided as partial eta squared (η_p^2) and Cohen's *d*. Alpha was set at $p = 0.05$, two-tailed. For every participant, trials with incorrect responses or outliers were removed for the RT analysis. Outliers were defined as RTs that deviated more than 3 SDs from the individual mean RT for the 0-back and 2-back separately (Cromheeke & Mueller, 2016).

Results

Group Characteristics

Fourteen subjects from the depressed group (13%) compared to one of the healthy group (1%) were excluded, because they failed to reach a minimum accuracy rate of 60% on the practice blocks of the 2-back task and thus did not continue with the experimental blocks, $\chi 2$ (1, 110) = 13.19, $p < .001$. As a result, the task was completed by 27 adolescents meeting DSM-5 criteria for MDD current ($n = 20$) or past ($n = 7$) (20 girls; $M_{\text{age}} = 14.81$, $SD = 1.64$) and 49 healthy adolescents (28 girls; $M_{\text{age}} = 14.33$, $SD = 1.57$). There were no significant differences between the included and excluded depressed adolescents on depressive symptoms (CDI) or anxiety symptoms (STAI-TC), $F(2, 44) = .639$, $p = .532$, $\eta^2 = .03$. In the final sample, depressed adolescents had significantly elevated CDI scores relative to comparisons, $F(1, 65) = 77.31$, $p < .001$, $\eta_p^2 = .54$. One-way ANOVAs also indicated significant group differences on STAI-TC, $F(1, 65) = 65.81$, $p < .001$, $\eta_p^2 = .50$, total problem scores on CBCL, $F(1, 60) = 77.78$, $p < .001$, $\eta_p^2 = .56$, and intelligence as measured with two subtasks from the WISC-III, (1, 65) = 16.66, $p < .001$, $\eta_p^2 = .20$. No significant group differences were present for age or gender distribution (all $p > .14$) (Table 1). Regarding the clinical characteristics of the depressed sample, scores on the DSM-oriented scales of CBCL indicated that anxiety problems were the most frequent comorbid condition in the depressed sample (26%).

Table 1

Characteristics of the Sample

	Depressed	Healthy
N	27	49
CDI***	20.54 (9.80)	6.39 (3.55)
STAI-TC***	45.14 (6.55)	31.77 (5.94)
CBCL Total Problems***	63.86 (30.21)	16.72 (11.50)
Age	14.81 (1.64)	14.33 (1.57)
Intelligence***	16.84 (4.78)	21.18 (3.72)
Sex (female/male)	20/7	28/21

Note. SDs are shown in parentheses. CDI = Children's Depression Inventory; STAI-TC = State-Trait Anxiety Inventory for Children (trait version); CBCL = Child Behavior Checklist; Intelligence = An intelligence score was calculated by summing the standard scores on Vocabulary and Block design for each participant.

$^{***}p < .001$

Reaction Time

As expected, a significant four-way interaction among Load, Condition, Emotion, and Group emerged[1], $F(2, 140) = 4.62$, $p = .011$, $\eta_p^2 = .06$. To explore this result, an ANCOVA with Condition and Emotion as within-factors and Group as between-subjects factor was run for the low load WM condition (0-back) and the high load WM condition (2-back), separately (Figure 2). Only during high WM load results revealed a significant three-way Condition by Emotion by

[1] The four-way interaction remained significant when excluding previously depressed adolescents (i.e., diagnosed with a major depressive disorder in the past) from the depressed group, $F(2, 128) = 3.14$, $p = .047$, $\eta_p^2 = .05$.

Group interaction, $F(2, 140) = 6.69$, $p = .002$, $\eta_p^2 = .09$. To understand this three-way interaction, a Condition by Emotion analysis of variance (ANOVA) was run for depressed and healthy adolescents, separately. In depressed adolescents no significant findings emerged (all *p*s >.14). In healthy adolescents, the Condition by Emotion interaction was significant, $F(2, 96) = 8.85$, $p < .001$, $\eta_p^2 = .16$, indicating slower RTs for happy faces in the gender relative to the valence condition, $t(48) = 3.69$, $p = .001$, $d = .51$. No differences were found for angry or neutral faces. Analyses within Conditions revealed slower RTs for happy faces when compared to angry faces, $t(48) = 2.09$, $p = .042$, $d = .31$, and neutral faces, $t(48) = 3.01$, $p = .004$, $d = .43$, in the gender condition. In the valence condition, RTs were faster for happy faces compared to angry faces, $t(48) = -2.97$, $p = .005$, $d = - .43$, and neutral faces, $t(48) = -2.11$, $p = .04$, $d = -.43$.

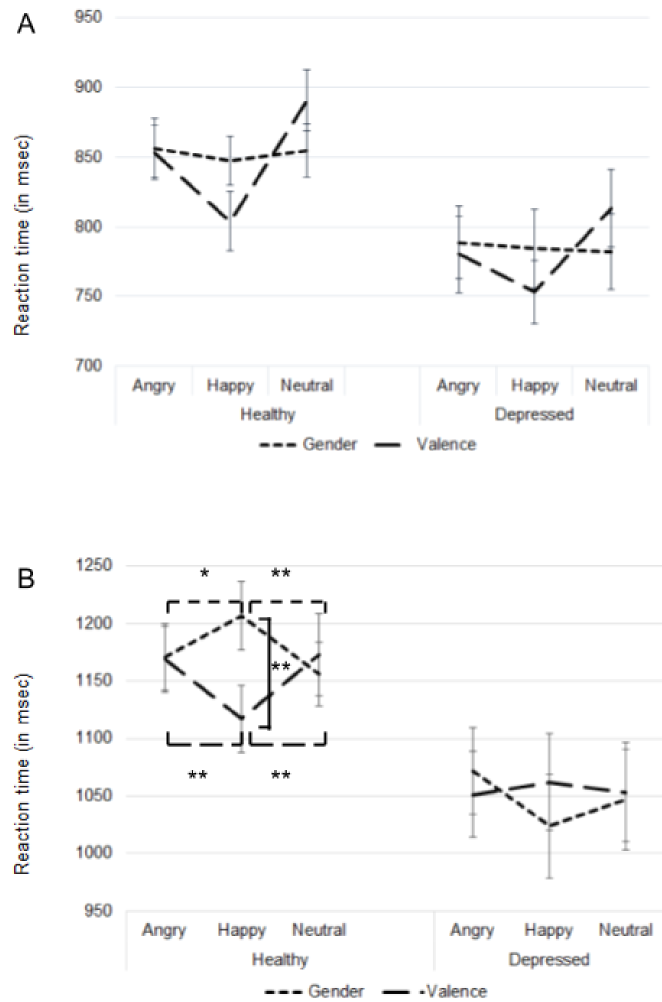

Fig 2 *(*A) RTs (ms) for healthy adolescents (left panel) and depressed adolescents (right panel) in the 0-back task. (B) RTs (ms) for healthy adolescents (left panel) and depressed adolescents (right panel) in the 2-back task. Error bars represent standard error of the mean

$^{*}p < .05$; $^{**}p < .01$

In order to compare the effects of happy faces between depressed and healthy adolescents, one-way ANOVAs were conducted on RT difference scores (DS; RT happy faces in valence condition - RT happy faces in gender condition). This DS was significantly larger in healthy adolescents compared to depressed adolescents, $F(1, 75) = 9.81$, $p = .002$, $\eta^2 = .12$. In addition, DS within Conditions were calculated. The DS between happy and angry faces, $F(1, 75) = 8.57$, $p = .005$, $\eta_p^2 = .10$, and between happy and neutral faces, $F(1, 75) = 6.56$, $p = .012$, $\eta_p^2 = .08$, were larger in healthy adolescents compared to depressed adolescents in the gender condition. Also in the valence condition, the DS were larger in healthy adolescents compared to depressed adolescents, (happy-angry: $F(1, 75) = 4.25$, $p = .043$, $\eta_p^2 = .05$; happy-neutral: $F(1, 75) = 4.54$, $p = .036$, $\eta_p^2 = .06$) (Figure 3).

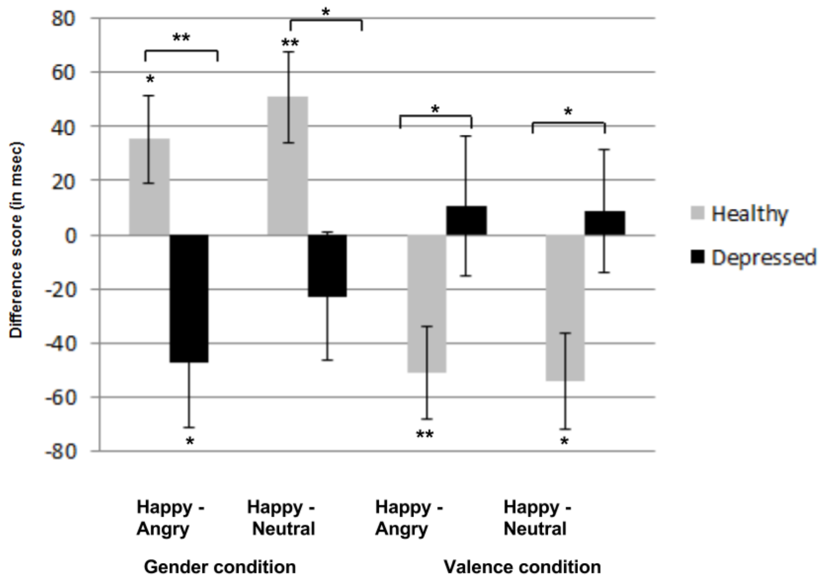

Fig 3 RT difference scores (ms) for the gender and the valence condition in both the healthy and the depressed group. Positive scores indicate slower RTs to happy faces compared to either angry or neutral faces. Error bars represent standard error of the mean

$^{*}p < .05$; $^{**}p < .01$

Response Accuracy

In the accuracy data (Table 2), Load interacted with intelligence, $F(1, 70) = 7.09$, $p = .01$, $\eta^2 = .09$. Follow-up analyses showed that intelligence correlated positively with accuracy rates on the 2-back task, $r(73) = .37$, $p = .001$, while there was no significant correlation with accuracy rates on the 0-back task, $r(73) = .05$, $p = .677$. However, the expected four-way interaction among Load, Condition, Emotion, and Group did not emerge[2].

Effects of Depressive and Anxiety Symptom Severity

[2] The findings on accuracy remained the same when excluding previously depressed adolescents (i.e., diagnosed with a major depressive disorder in the past) from the depressed group.

CDI and STAI-TC scores were not significantly correlated with the different performance variables (all *p*s > .05 after correction for multiple comparisons).

Table 2

Mean RTs (mean and SD, in ms) and accuracy rates (mean and SD, in %) on the 0-back task (upper half) and the 2-back task (lower half) as a function of group.

Note. SDs are shown in parentheses; RT = Reaction Time; ACC = accuracy rates

		Depressed		**Healthy**	
0-back task					
Condition	**Emotion**	**RT**	**ACC**	**RT**	**ACC**
Gender task	Angry	789 (136)	86 (11)	856 (417)	87 (10)
	Happy	784 (147)	90 (9)	844 (121)	91 (9)
	Neutral	782 (141)	92 (10)	852 (133)	92 (6)
Valence task	Angry	780 (144)	90 (7)	850 (135)	89 (8)
	Happy	753 (117)	93 (9)	802 (145)	94 (7)
	Neutral	813 (145)	94 (8)	887 (153)	92 (8)
2-back task					
Gender task	Angry	1071 (197)	63 (12)	1165 (201)	67 (9)
	Happy	1024 (234)	67 (11)	1201 (206)	69 (11)
	Neutral	1047 (229)	69 (15)	1150 (195)	69 (11)
Valence task	Angry	1051 (195)	66 (14)	1163 (203)	67 (12)
	Happy	1062 (218)	68 (16)	1112 (204)	71 (15)
	Neutral	1053 (222)	68 (16)	1166 (251)	68 (13)

Discussion

This study investigated the effects of relevant and irrelevant emotional stimuli on WM in depressed and healthy adolescents. Contrary to expectations, angry faces did not influence WM performance in depressed adolescents. However, as hypothesized, happy faces affected WM performance in healthy adolescents, whereas this effect was not present in depressed adolescents. Specifically, in healthy adolescents, happy faces led to faster RTs in the valence condition and to slower RTs in the gender condition compared to angry and neutral stimuli and in comparison with depressed adolescents. In addition, correlation analyses revealed that there were no significant associations between depressive or anxiety symptomatology and task performance variables.

Overall, within the context of WM, the current results suggest that depressed adolescents do not show a preferential processing of negative faces, but rather fail to demonstrate a memory bias to positive faces as seen in healthy comparisons. This is in-line with parallel research in attention (Ellis, Beevers, & Wells, 2011; McCabe & Gotlib, 1995), WM (S. M. Levens & Gotlib, 2009), and self-referent encoding and recall (Timbremont & Braet, 2004) indicating that depressed or dysphoric individuals do not show biases while healthy participants exhibit a positivity bias. In addition, the results in the comparison group correspond to previous studies in which positive information affected WM performance in healthy individuals (Ladouceur et al., 2005; S. M. Levens & Gotlib, 2010; Mueller et al., 2017). The finding that in depressed adolescents WM processes do not lead to a positivity bias that is evident in healthy adolescents converges with the positive attenuation hypothesis (Rottenberg, Gross, & Gotlib, 2005). In essence, this hypothesis suggests that depressed individuals show a blunted reactivity or insensitivity to positive information compared to healthy comparisons. This insensitivity for positive information may be a mechanism reflecting the interpersonal difficulties that are associated with depression (Hames et al., 2013). Specifically, it can be hypothesized that depressed adolescents attend positive social information to a lesser extent compared to healthy adolescents, which may in turn result in the perception of a lack of social support and a low self-esteem (Gotlib & Hammen, 2002; Joormann & Gotlib, 2007).

In contrast to our findings in WM, previous studies in depressed or dysphoric youth demonstrated a preference towards angry or threatening faces in attention (Hankin, Gibb, Abela, & Flory, 2010) or affective priming (Wante, Mueller, Demeyer, De Raedt, & Braet, 2015). The explanation for these contradictory results may be found in the focus on different cognitive control functions (i.e., selective attention and inhibition vs. WM). Previous work has provided evidence that distinct cognitive control functions, such as inhibition and WM, are moderately correlated but yet are clearly distinct from one another (Miyake et al., 2000) and show different developmental trajectories (Best & Miller, 2010). Furthermore, the results in the depressed group also differ from prior n-back studies that used emotional stimuli as distractors and non-emotional stimuli as target stimuli (Ladouceur et al., 2005; Tavitian et al., 2014). The present study differed from these prior two studies in two crucial ways: 1) we assessed both relevant and irrelevant emotional information, and 2) the two tasks (gender/valence) were contained within the same stimuli as opposed to separated distractor and target stimuli. Therefore, the diverging results may be explained by the different nature of the tasks and/or stimuli involved.

In any case, the findings are in-line with theoretical notions of how affective information should influence high cognitive load and WM (Eysenck et al., 2007; Lavie, 2010). According to the Attentional Control Theory (ACT; Eysenck et al., 2007), affective information should only influence cognitive control processes when cognitive load is high. In the current study, the beneficial effect of happy faces in task-relevant conditions was only observed in the high load WM task, which suggests that healthy adolescents experience difficulties filtering positive information especially when task demands are high and cognitive resources are limited.

A final important finding is that self-reported depressive and anxiety symptoms were not significantly associated with WM performance. This is in line with existing literature on cognitive control processes in depressed, dysphoric or anxious adolescents (Jazbec, McClure, Hardin, Pine, & Ernst, 2005; Kavanaugh & Holler, 2014; Mueller et al., 2015; Sommerfeldt et al., 2016; Wante et al., 2015) and indicates the level of emotional WM impairments is not dependent on the severity of depressive or anxiety symptomatology but may rather represent a primary cognitive feature and a stable marker of a depressive disorder in adolescents.

Clinically, the present results suggest an important role of emotional processing in WM in future prevention or intervention programs for adolescent depression. Notably, a significantly larger proportion of the depressed group compared to the healthy group failed to reach a minimum accuracy rate of 60% on the practice blocks of the high load WM task. This finding points to a general WM impairment in depressed adolescents and corresponds to previous studies indicating general cognitive control deficits in depressed versus healthy adolescents (for a review see Wagner, Muller, Helmreich, Huss, & Tadic, 2015). A cognitive control training (CCT) targeting general WM capacity may improve goal-directed and adaptive behavior in a changing environment in at-risk or depressed adolescents (Gyurak, Goodkind, Kramer, Miller, & Levenson, 2012). Research in adults already provided evidence for a significant effect of CCT targeting WM on ER and stress reactivity (Hoorelbeke, Koster, Vanderhasselt, Callewaert, & Demeyer, 2015; Siegle, Ghinassi, & Thase, 2007). However, parallel research in depressed adolescents focusing on WM is currently lacking.

Furthermore, emotional processing in WM may be related to the emotion regulation (ER) difficulties that typically characterize depressed adolescents (S. M. Levens & Gotlib, 2009). Specifically, in real life, when different emotional stimuli are attracting attention, reduced attention for positive information may hinder the use of adaptive ER strategies, such as positive refocusing, and lead to an exacerbation of negative affect (Sanchez, Vazquez, Gomez, & Joormann, 2014). In this context, an interesting avenue for future research is to explore the impact of a training tailored at enhancing attention towards positive information on ER in depressed adolescents. Based on a review of Wadlinger and Isaacowitz (2011), it can be assumed that orienting attention towards positive information can be trained and can be effective in enhancing emotional well-being and ER ability.

Some study limitations should be noted. First, in contrast to multiple studies (e.g., Joormann & Gotlib, 2007; S. M. Levens & Gotlib, 2010) that focused on cognitive control over sad stimuli, the current study investigated the effect of angry facial expressions on WM in depressed adolescents. Since sad faces were not included in our stimulus set, we could not compare the effects of different types of negative stimuli on WM performance. In addition, the depressed group in this study included both currently depressed and remitted depressed adolescents. Although altered cognitive processing of emotional information is suggested to be a vulnerability factor which is present in both acute and remitted stages of a major depressive disorder (Demeyer, De Lissnyder, Koster, & De Raedt, 2012; Joormann & D'Avanzato, 2010; Kertz, Belden, Tillman, & Luby, 2016), effects may have been stronger and clearer in a more homogeneous sample exclusively consisting of currently depressed adolescents. Moreover, a substantial number of depressed participants (13%) were excluded due to poor performance on the practice trials of the 2-back task. This may have implications on the representativeness of the sample as adolescents with the lowest levels of WM functioning were not able to complete the n-back task. Finally, the current study is limited by the cross-sectional nature of its design preventing definitive conclusion whether impaired WM performance and the absence of a positivity bias prospectively lead to the development of a depressive disorder.

Conclusions

Based on the results of the current study, it can be concluded that depressed adolescents do not show a biased processing of negative information, but rather lack a protective positivity bias, which is typically observed in healthy adolescents. These findings suggest that the processing of positive emotional information in WM may be a promising target for future depression prevention and treatment programs. Further research that examines the prospective effects of impaired WM on adolescent depression is warranted.

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Conflict of interest

The authors declare that they have no conflict of interest.

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